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**A Note on Post-stratification when  
Analyzing Binary Survey Data  
Subject to Non-response**

Discussion  
Papers

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## **A Note on Post-stratification when Analyzing Binary Survey Data Subject to Non-response**

**Abstract:**

In this paper we follow up two notes of Thomsen (1973, 1978) and present some results on the estimation effect of post-stratification when analyzing binary survey data subject to non-response. Using an alternative parameterisation and assuming that the non-response depends on the variable of interest which can not be fully observed, we show that the relative reduction in the bias can be estimated from the response group alone. In addition, the relative bias and variance reduction are both shown to be approximately equal, under certain conditions, to one minus the square of the correlation coefficient between the auxiliary and object variable among the respondents.

**Keywords:** Post-stratification, non-response, non-ignorable, non-response

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# 1 Introduction

Non-response, or missing observations, is a common problem with survey data. Thomsen (1973) showed that the bias of the observed sample mean admits a decomposition,  $B + A$ , of which component  $B$  “arises from the fact that different groups in the population have different response rates”, whereas  $A$  is “due to the biasing effect of non-response within each group”. Since component  $B$  vanishes with the post-stratified mean, weighting subclass means reduces the bias caused by non-response whenever (i)  $B$  and  $A$  have the same sign, or (ii)  $B$  and  $A$  have different signs but  $2|A| < |B|$ . Notice that the size of the bias, however, is unknown in general since component  $A$  depends on the mean within the non-response data, which can not be estimated without further assumptions. While, as explained in Thomsen (1973), the results apply whether the marginal proportions of the subclasses are known or not. Adopting a “broadly defined” (Smith 1991) sense of the term, we simply refer to the method as post-stratification.

In this note, we concentrate on binary data, which allows an alternative resolution of the bias caused by non-response. In particular, it will be shown that it is sometimes possible to assess the bias in both methods based on the response group alone, even though the non-response is assumed to be non-ignorable in the sense of Rubin (1976) and Little and Rubin (1987) such that the mean of the variable to be estimated actually differs from the respondents to the non-respondents. In fact, the relative reduction in the bias due to post-stratification is in certain cases approximately equal to the relative reduction in the variance. As in Thomsen (1973), we assume simple random sampling throughout.

In the final section the result obtained here are applied to the data of the Norwegian Labour Force Survey (LFS).

## 2 Alternative resolution of the bias due to non-response

Denote by  $U = \{1, \dots, N\}$  the population, and by  $s = \{1, \dots, n\}$  the sample. Assume that we are to estimate the population mean of a binary variable, denoted by  $\bar{Y}$ ; and that auxiliary information is available in the form of a second binary variable denoted by  $X$ . In addition, denote by  $R$  the response variable such that  $R_i = 1$  indicate response of the  $i$ th unit and  $R_i = 0$  non-response. Thomsen (1973) stratified the sample according to the values of  $(X, R)$ , and expressed the overall observed sample mean  $\bar{y}$  and the post-stratified mean  $\bar{y}_{pst}$  as a function of  $\bar{y}(X, R)$ , with the help of the marginal proportions  $n(X)/n$  and  $n(X, R)/n(X)$ .

Considering non-response as dependent on  $(X, Y)$ , we cross-classify the population according to

$(X, Y)$  instead. Denote by  $q_{ij} = N_{ij}/N$  the population proportion of  $(X, Y) = (i, j)$  for  $i, j = 0, 1$ , and  $r_{ij}$  the non-response rate within the population group  $(X, Y) = (i, j)$ . The population and the expected sample has the following distribution:

	$Y = 1$		$Y = 0$	
	$R = 1$	$R = 0$	$R = 1$	$R = 0$
$X = 1$	$q_{11}(1 - r_{11})$	$q_{11}r_{11}$	$q_{10}(1 - r_{10})$	$q_{10}r_{10}$
$X = 0$	$q_{01}(1 - r_{01})$	$q_{01}r_{01}$	$q_{00}(1 - r_{00})$	$q_{00}r_{00}$

The population mean  $\bar{Y}$  is given as  $p = q_{11} + q_{01}$ , and the marginal proportion of  $X = 1$  as  $q = q_{11} + q_{10}$ . Given non-response, i.e.  $s = (s_r, s_{mis})$  where  $s_r$  denotes the response group and  $s_{mis}$  the non-response group with the respective size  $n_r$  and  $n - n_r$ , the observed sample mean is given as  $\bar{y} = [n_r(1, 1) + n_r(0, 1)]/n_r$ , where  $n_r(i, j)$  denotes the size of the subsample  $(X, Y) = (i, j)$  within the response group  $s_r$ , and

$$(1) \quad E[\bar{y} - p | n_r] = \frac{\sum_{i,j} q_{i1}q_{j0}(r_{j0} - r_{i1})}{\sum_{i,j} q_{ij}(1 - r_{ij})} = \frac{p(\sum_i q_{i0}r_{i0}) - (1 - p)(\sum_i q_{i1}r_{i1})}{E[n_r]/n} = E[\bar{y} - p].$$

While the first equation expresses the bias as a function of pairwise difference in response rates, the second one specifies the contribution of each subsample  $(X, Y)$ .

Post-stratification further divides the response group into  $s_r = (s_{r,1}, s_{r,0})$  with the respective size  $n_{r,1}$  and  $n_{r,0}$ . The post-stratified mean is  $\bar{y}_{pst} = qn_r(1, 1)/n_{r,1} + (1 - q)n_r(0, 1)/n_{r,0}$ , and

$$(2) \quad E[\bar{y}_{pst} - p | (n_{r,1}, n_{r,0})] = \frac{q_{11}q_{10}(r_{10} - r_{11})}{E[n_{r,1}]/n} + \frac{q_{01}q_{00}(r_{00} - r_{01})}{E[n_{r,0}]/n} = E[\bar{y}_{pst} - p].$$

This provides an alternative expression of component  $A$  (Thomsen 1973) under the present settings. In case  $q$  is unknown and is estimated by  $n_1/n$  where  $n_1$  is the size of the sample post-stratum  $X = 1$ , the result is valid under suitable regularity conditions.

Notice that while the values of (1) and (2) are unknown in general, one sometimes can be quite certain about their signs. For instance, if it known that, conditional to  $X = i$ ,  $Y = 1$  leads to lower non-response rate, then  $\bar{y}_{pst}$  is upward biased according to (2).

In contrast to the bias, Thomsen (1978) derived in “a second note” the respective approximate variances of  $\bar{y}$  and  $\bar{y}_{pst}$ , which can be estimated from the observed sample directly regardless of the values of  $r_{ij}$ . It was noted that the variance reduction is often not noteworthy unless with known population marginal proportions of the post-strata. With the present notations and ignoring the finite population

correction factors, these are given as

$$Var(\bar{y}) = E[n_r(1, 1) + n_r(0, 1)] \cdot E[n_r(1, 0) + n_r(0, 0)] / E[n_r]^3$$

$$Var(\bar{y}_{pst}) = q^2 E[n_r(1, 1)] \cdot E[n_r(1, 0)] / E[n_{r,1}]^3 + (1 - q)^2 E[n_r(0, 1)] \cdot E[n_r(0, 0)] / E[n_{r,0}]^3,$$

In particular, the ratio of the variances, denoted by  $\eta = Var(\bar{y}_{pst}) / Var(\bar{y})$ , describes the estimation effect of the post-stratification on the variance.

### 3 Ignorable and non-ignorable non-response

Basically, with auxiliary information  $X$  being available, non-response is ignorable if  $R$  is independent of  $Y$  given  $X$ , whereas it is non-ignorable if  $R$  remains dependent of  $Y$  despite the knowledge of  $X$ . With the present notation, ignorable non-response implies  $r_{i0} = r_{i1}$  for  $i = 0, 1$ . It follows from (2) that the post-stratified mean is in such cases unbiased, whereas the sample mean remains biased. Indeed, its bias can simply be estimated by  $\bar{y} - \bar{y}_{pst}$ .

Meanwhile, the simplest non-ignorable non-response here is to assume that  $R$  is independent of  $X$  given  $Y$ , which implies that  $r_{i0} = r_0$  and  $r_{i1} = r_1$  for  $i = 0, 1$ . It follows from (1) that the bias in  $\bar{y}$ , denoted by  $b_{srs}$ , is now given by

$$(3) \quad b_{srs} = \frac{(r_0 - r_1)p(1 - p)}{E[n_r]/n} = \frac{r_0 - r_1}{(1 - r_0)(1 - r_1)} \cdot \frac{1}{n} \left\{ \frac{E[n_r(-, 1)]E[n_r(-, 0)]}{E[n_r]} \right\},$$

where  $n_r(-, j) = n_r(1, j) + n_r(0, j)$  for  $j = 0, 1$ . Whereas the bias in  $\bar{y}_{pst}$ , denoted by  $b_{pst}$ , is similarly given by (2) as

$$(4) \quad b_{pst} = \frac{r_0 - r_1}{(1 - r_0)(1 - r_1)} \cdot \frac{1}{n} \left\{ \frac{E[n_r(1, 1)]E[n_r(1, 0)]}{E[n_{r,1}]} + \frac{E[n_r(0, 1)]E[n_r(0, 0)]}{E[n_{r,0}]} \right\}.$$

In other words, the ratio of the bias, denoted by  $\gamma = b_{pst}/b_{srs}$  or  $A/(B + A)$  in the notation of Thomsen (1973), can be estimated from the response group alone. Since  $\bar{y} - \bar{y}_{pst}$  is an estimate of  $b_{srs} - b_{pst}$ , a bias-correcting estimator is now given as

$$(5) \quad \bar{y}_{adj} = -\frac{\hat{\gamma}}{1 - \hat{\gamma}}\bar{y} + \frac{1}{1 - \hat{\gamma}}\bar{y}_{pst}.$$

To actually apply  $\bar{y}_{adj}$ , one must check on the non-response assumption  $r_{i0} = r_0$  and  $r_{i1} = r_1$  for  $i = 0, 1$ , e.g. through the goodness-of-fit from a model point of view. More explicitly, consider the sample as having been generated under the model where  $P[(X, Y) = (i, j)] = q_{ij}$  and  $P[R = 0 | (X, Y) = (i, j)] = r_{ij}$ , and thereby obtaining the likelihood function proportional to  $P[(X, Y, R)]$  on which the statistical inference can be based. However, one must keep in mind that a good fit alone is not

enough to establish the validity of the model. For instance, the ignorable non-response model  $r_{i0} = r_{i1}$  always fits perfectly to the data, i.e. reproducing the data exactly. On the other hand, it is probably reasonable to accept a bad fit as the convincing evidence *against* the non-response assumption. In any case, the results above suggest a general methodology for the full adjustment of the bias, i.e. to find some “instrumental” variable  $X$  which, while being reasonably correlated with  $Y$  — so that  $1 - \hat{\gamma}$  is not too close to zero, is however independent of, or “non-informative” on, non-response  $R$  conditional to  $Y$ .

It is interesting that, under the present non-response assumptions,  $\gamma = \eta$  provided  $E[n_{r,1}]/E[n_r] = q$  and  $E[n_{r,0}]/E[n_r] = 1 - q$ , i.e. the ratio of the bias equals to the ratio of the variances. Since  $q = E[n_1]/n$ , the equality holds approximately in cases where the non-response is not too severe. In addition, it is sometimes the case that  $q \doteq p$ , such as when  $X$  is provided by a similarly defined variable available from other sources or simply the variable  $Y$  some short while ago. If this approximate equality holds also within the response group, we obtain

$$(6) \quad \gamma \doteq \eta \doteq 1 - \rho_r^2 \quad \rho_r = \frac{E[n_r(1,1)] \cdot E[n_r] - E[n_r(1,-)] \cdot E[n_r(-,1)]}{\sqrt{\{E[n_r(1,-)] \cdot E[n_r(0,-)]\} \{E[n_r(-,1)] \cdot E[n_r(-,0)]\}}},$$

where  $\rho_r$  is the correlation coefficient between  $X$  and  $Y$  among the respondents. Having estimated  $(\rho_r, \gamma, \eta)$ , one can easily check whether the (6) holds in a given situation.

## 4 An example: the Norwegian LFS

Post-stratification has long been applied in connection with the LFS in a number of countries. By exploiting the high correlation between the Register-based Employment/Unemployment Status and the LFS Employment/Unemployment Status, post-stratification can greatly reduce the variance of the level-estimators (e.g. Djerf 1997). Meanwhile, since one can be quite certain that the Employment rate is lower among the non-respondents, also when conditional to each state of the Register-based Status, the non-response in the LFS is most likely non-ignorable. Proceeding under the assumption that the LFS non-response (denoted by  $R$ ) is independent of the Register-based Employment Status (denoted by  $X$ ) conditional to the LFS Employment Status (denoted by  $Y$ ), we may apply the results above and study the effect on bias-reduction *via* post-stratification.

We illustrate with the data of the first quarter in 1995 from the Norwegian LFS:

$X = 1$			$X = 0$		
$(Y, R) = (1, 1)$	$(Y, R) = (0, 1)$	$R = 0$	$(Y, R) = (1, 1)$	$(Y, R) = (0, 1)$	$R = 0$
12881	1158	518	1829	6726	796

First of all, a simple calculation based on these data gives us  $\hat{\eta} = 0.494$ , i.e. an estimated 50% reduction in variance due to post-stratification w.r.t. the Register-based Employment Status, which is consistent with the findings presented in Djerf (1997). Also,  $\hat{\rho}_r = 0.716$  and  $1 - \hat{\rho}_r^2 = 0.487 \doteq \eta$ . All the estimates here are obtained by replacing  $E[n_r(i, j)]$  with  $n_r(i, j)$ .

Now, applying the results on the bias, we obtain  $(\bar{y}, \bar{y}_{pst}, \bar{y}_{adj}) = (0.651, 0.645, 0.640)$  with the known  $q = 0.613$  in the population, and  $(\bar{y}, \bar{y}_{pst}^*, \bar{y}_{adj}^*) = (0.651, 0.642, 0.634)$  now with  $\hat{q}^* = 0.609$  estimated from the sample. Whereas  $\hat{\gamma} = 0.487 = 1 - \hat{\rho}_r^2$  in both cases. Notice that the difference between  $\bar{y}_{pst}$  and  $\bar{y}_{pst}^*$  is doubled into that between  $\bar{y}_{adj}$  and  $\bar{y}_{adj}^*$  through the term  $1/(1 - \hat{\gamma})$ , which indicates the sensitivity of  $\bar{y}_{adj}$  towards the stochastic variation in the estimation of  $(\gamma, b_{srs} - b_{pst})$ .

We then evaluated the non-response assumption  $r_{i0} = r_0$  and  $r_{i1} = r_1$  for  $i = 0, 1$  from a model perspective as explained earlier. More explicitly, we calculated the maximum likelihood estimates applying the EM algorithm, which gives us  $(\hat{q}_{11}, \hat{q}_{01}, \hat{r}_1, \hat{r}_0) = (0.559, 0.078, 0.029, 0.099)$ . The deviance, i.e. twice the difference between the maximum attainable log-likelihood and the fitted log-likelihood, was zero so that these also yielded the perfect fit to the data. Notice that, from the model perspective, we have  $\bar{y}_{mod} = \hat{q}_{11} + \hat{q}_{01} = 0.637$ . To check whether the perfect fit could be attained with any choice of  $X$ , we have also fitted the model where  $X$  was set to be Sex instead. Using the known  $q = 0.503$  in the population, we obtained  $(\hat{q}_{11}, \hat{q}_{01}, \hat{r}_1, \hat{r}_0) = (0.363, 0.307, 0.082, 0.000)$  with deviance 10.3, so that we can be quite sure that the non-response assumption does not apply to Sex. (Post-stratification w.r.t. Sex gives  $\hat{\eta} = 0.987$ , i.e. with practically no effect on the variance.)

To summarize the above findings, we do not recommend bias-correction *via*  $\bar{y}_{adj}$  for the Norwegian LFS due to its sensitivity towards the non-response assumption as well as the uncertainty in the estimation of  $(\gamma, b_{srs} - b_{pst})$ . For instance, it is probable in the case of LFS that non-response is indeed severer among the subsample  $(X, Y) = (0, 0)$  than among  $(X, Y) = (1, 0)$ , in which case  $R$  is not strictly independent of  $X$  conditional  $Y$ , though model fitting seems to suggest a very weak additional dependence in the eventual case. In contrast, it is likely a robust assessment that, using Register-based Employment Status, post-stratification results into about 50% of reduction in both the variance and the bias caused by non-response, of which the latter has taken into consideration the “non-ignorability” of the non-response.



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